Statistical Tools for Fitting Models of the Population Consequences of Acoustic Disturbance to Data from Marine Mammal Populations (PCAD Tools II)

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LONG-TERM GOALS

Our goal is to build an ecological modeling framework that facilitates understanding of the way in which at-sea condition and health of various species of marine mammals changes over time. This project will develop statistical tools to allow mathematical models of the population consequences of acoustic disturbance to be fitted to data from marine mammal populations. We will work closely with Phase II of the ONR PCAD Working Group, and will provide statistical support to that group.

OBJECTIVES

Our scientific objectives are to build a statistical framework for understanding the way in which at-sea health varies over time for (initially) three species of marine mammals: southern and northern elephant seals, and northern right whales. Should the Working Group decide that we should address additional species, e.g. bottlenose dolphins, we will take those up in turn.

For elephant seals our objective is to build and fit to data a hierarchical Bayesian model that provides daily estimates of lipid status. Maternal lipid status is a key variable in the life history of elephant seals, as it is strongly correlated with pup survival (McMahon et al. 2000). This model will use the drift dive behavior of elephant seals (Crocker et al. 1997) to provide observations on the underlying true, yet immeasurable, lipid state.

For right whales, our objective is to build a model that provides spatially and temporally explicit estimates of individual health, movement, and survival. The model builds upon some of the ideas from the elephant seal project, but as the photo-identification of individual right whales is the core of the data, the model also includes many ideas concerning mark/recapture from (Clark et al. 2005).

APPROACH

Work has focused on publishing manuscripts based on the elephant seal (Schick et al. 2013b) and right whale (Schick et al. 2013a) work, and on a detailed examination of the way in which relative changes in health are described in the right whale model. In addition, we have presented the results of our work at a variety of conference venues.

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For the elephant seals manuscript, we completed an examination of the possible use of the physics-based equations linking lipid to drift rate (Biuw et al. 2003) in the observation model. We concluded that we lacked the data to inform such a model. We submitted a manuscript to *Journal of Animal Ecology* last fall that included results from this analysis. Reviewers were satisfied with this approach, and we did not make substantive changes to the model previously submitted. The manuscript was accepted for publication this summer (Schick et al. 2013b).

For right whales, our work focused on completing and publishing the overview manuscript for the model we developed. This was published in *PLoS-ONE* this spring (Schick et al. 2013a). Following a trip by Schick to Boston in May, we undertook a thorough examination of the different facets of the health process model. Our goal was to develop a broader and deeper understanding of the meaning of relative indices of health across individuals and the whole population. Portions of this work will appear in the proceedings of a recent conference on The Effects of Noise on Aquatic Life (Schick et al. 2014).

In addition to this work, Schick has been working closely with Harwood and Fleishman in two different expert elicitation projects – offshore marine renewables in UK waters (Harwood et al. 2014) and the ship speed rule and its impact on right whales (Fleishman et al. 2014). Schick and Fleishman have also been organizing an additional elicitation that examines movements of right whales into and through the Mid-Atlantic region of their habitat range.

WORK COMPLETED

Much of our work this year has centered around the continuing development, refinement, and publication of the right whale model. Subsequent to the publication of the overview manuscript (Schick et al. 2013a), we have continued to develop four facets of the model in order to more completely quantify the health of individual right whales; 1) understanding the effects of imputing missing data; 2) using different values for process error for the health sub-component of the model; 3) testing the effect of informed priors for movement; and 4) the interplay between the priors and the starting health values in the MCMC chains. (N.B. the results of this work are described in detail in the Annual Report for N000141210389, and are not repeated here.)

We published the elephant seal lipids model this year (Schick et al. 2013b), and we used the lipids estimates from the model to examine the possible effects of disturbance (New et al. 2013, Costa et al. 2014).

In addition, Schick has worked with Doug Nowacek (Duke University) on a PCAD review manuscript (*In review* at Biological Conservation).

Thomas, Harwood, and Schick traveled to Sarasota, FL in January to participate in the second Phase II meeting of the PCAD working group. Schick has made research trips to New England Aquarium in Boston in January, May, and June of this year.

We have presented the work at the Right Whale Consortium Meeting (November), European Cetacean Society (April), a one-day workshop on statistical modelling in Lisbon, Portugal (April), the UK National Centre for Statistical Ecology annual workshop (June), and the Effects of Aquatic Noise conference (August). We will also present an update on the PCAD modelling, and the results from the Mid-Atlantic expert elicitation at the upcoming Right Whale Consortium Meeting in November.

RESULTS

In both right whale and elephant seal case studies, the estimates of a hidden process have provided a synthetic understanding of how animals fare over broad spatial and temporal scales. With elephant seals, the understanding has focused on aspects of foraging ecology (Schick et al. 2013b). For right whales we have quantified more precisely how the health of individuals and of the population change over time (Schick et al., 2103a) (Figures 1 and 2).

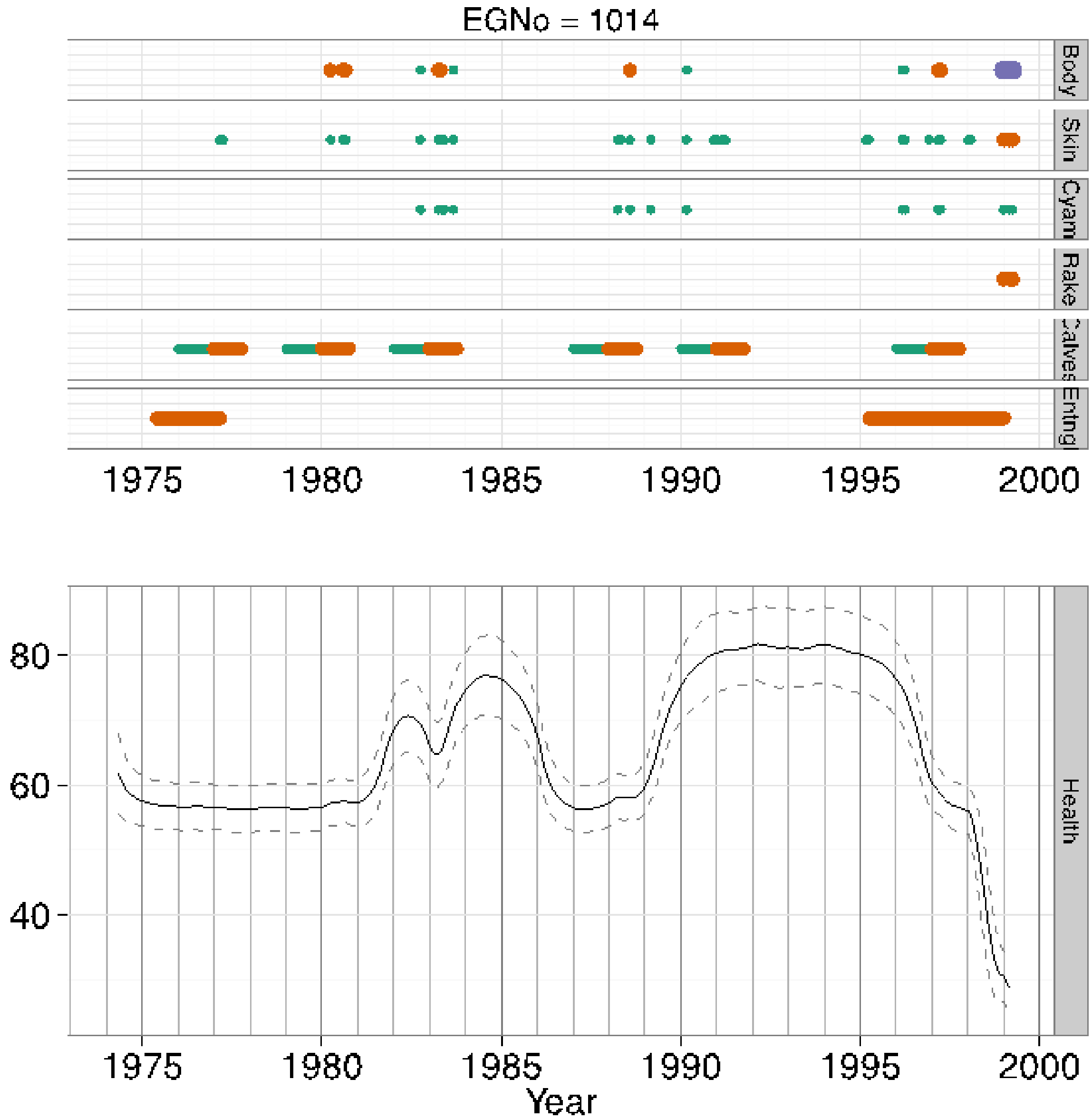

Figure 1. Health estimates (bottom panel) for right whale # EGNo 1014, with uncertainty, represented as solid and dashed black lines, respectively. Data observations are shown (top panels) for body fat, skin condition, presence of cyamids, presence of rake marks, gestational status, and entanglement. Observations where the animal is observed in poorer condition are shown with orange and purple dots. This animal is known to have died in 1999 following a ship strike.

In an effort to better understand the population level trend shown in Figure 2, we have been exploring average health for different stage classes of the population, e.g. lactating females, older juveniles, etc. This has identified those stage classes whose health reflects that of the entire population (adult males, Figure 3), and those whose health is notably different from the entire population (pregnant females, Figure 4).

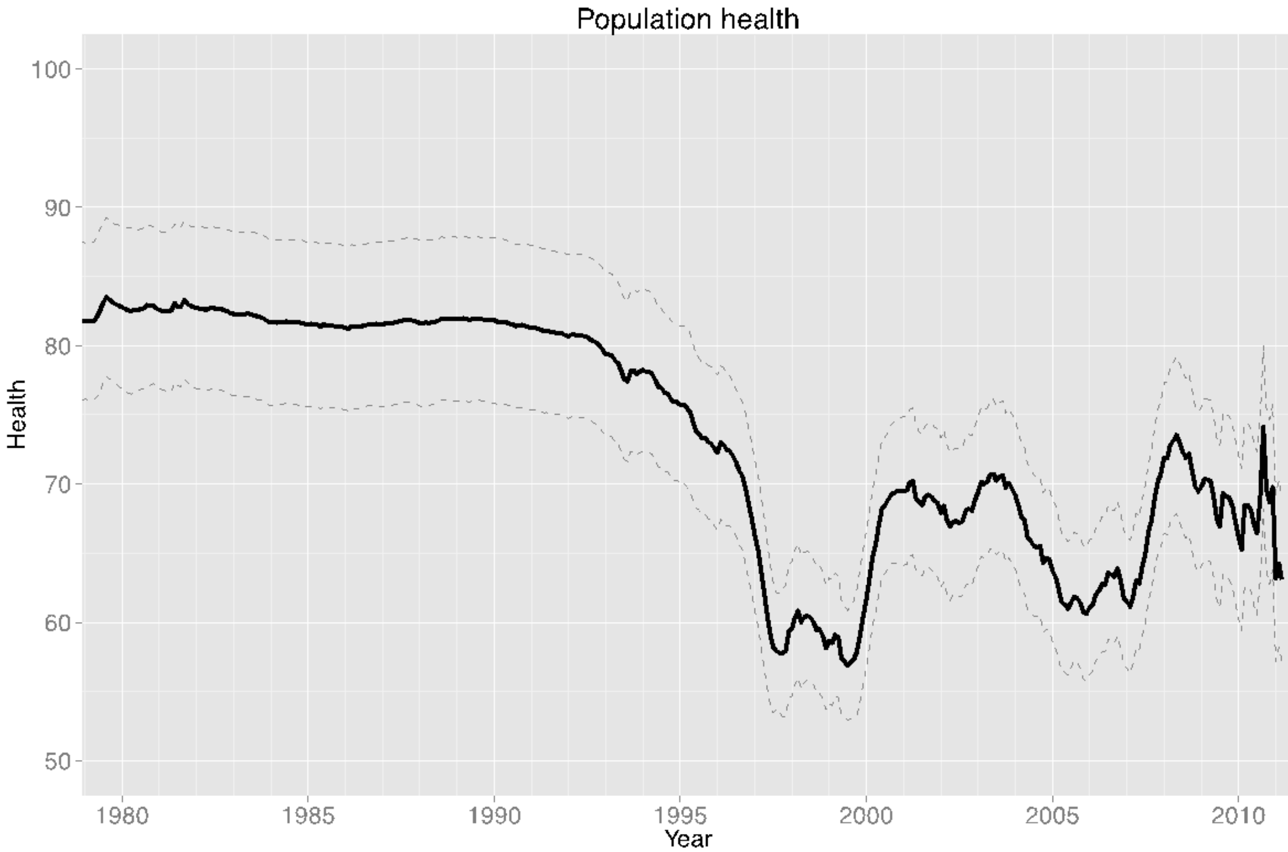

Figure 2. Estimates of population level health (a unit-less index) over 30 years. Following a stable period in the 1980's, health has been much more variable. Known periods of low vital rates in the late 1990's are reflected in the low mean health.

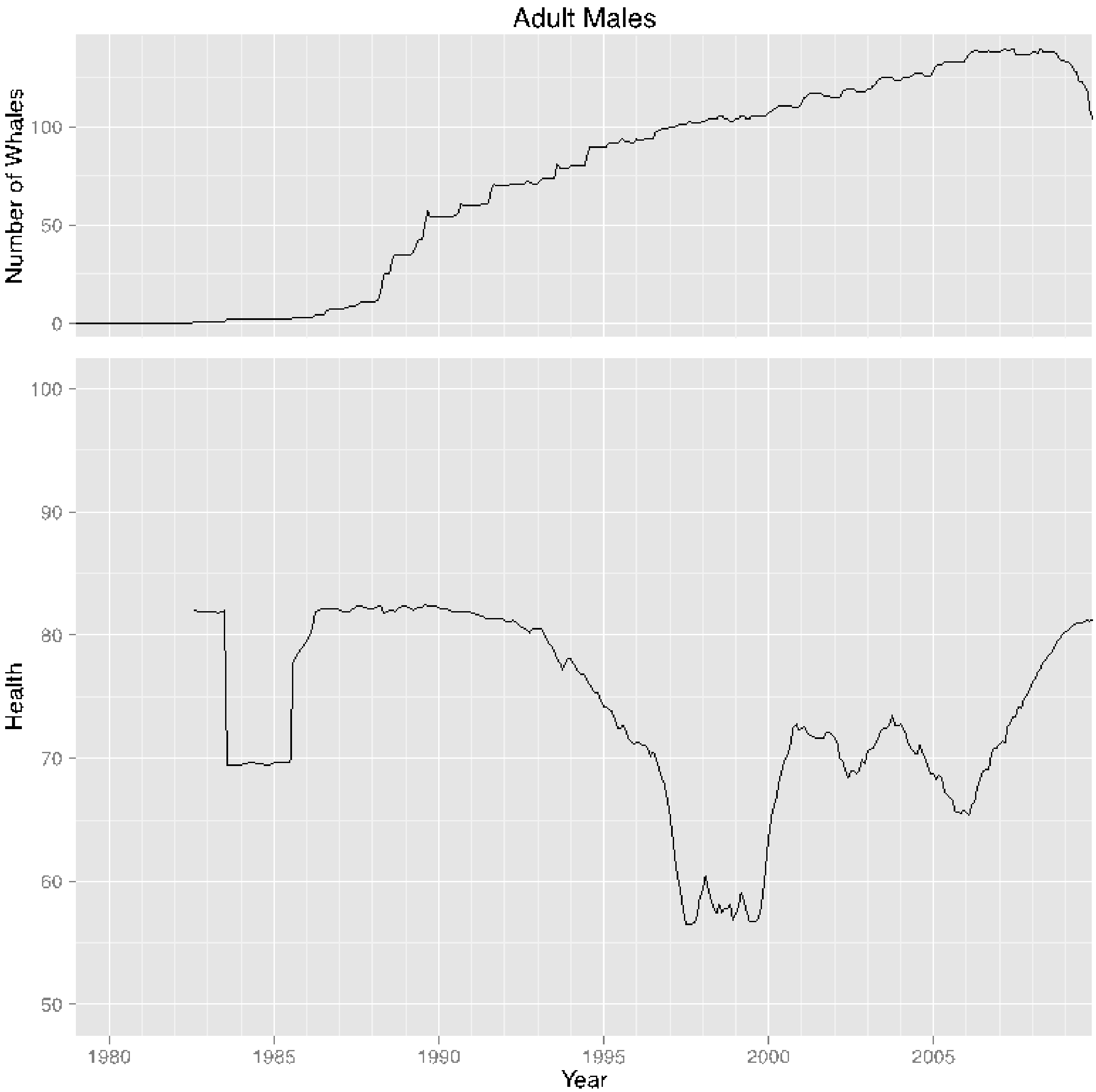

Figure 3. Estimates of health in adult male right whales over 30 years (lower panel). Following a stable period in the 1980's, health has been much more variable. However, following 2005, males seem to have recovered to previous levels of health. Number of adult males alive each year is shown in the top panel.

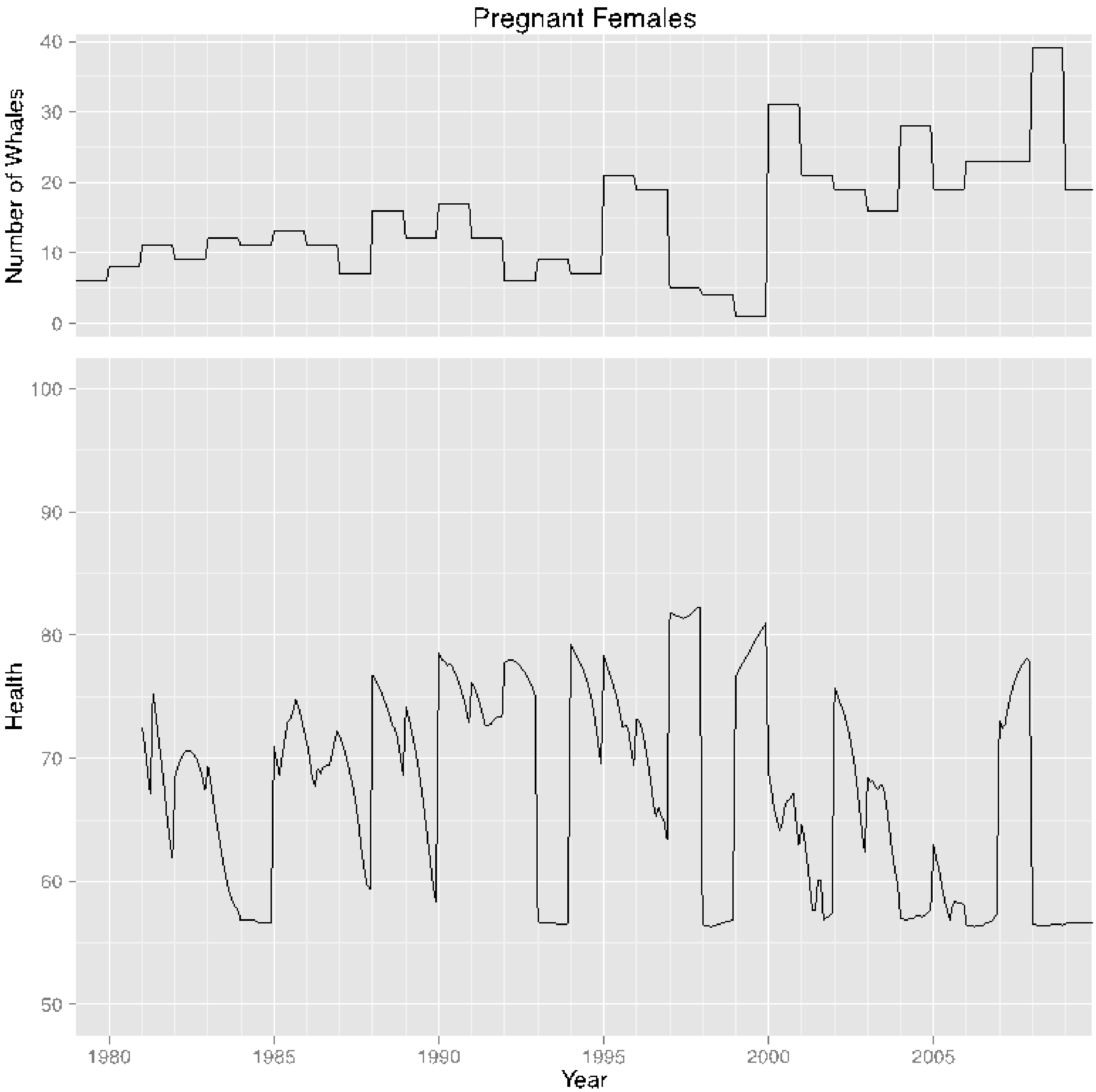

Figure 4. Estimates of health in pregnant female right whales over 30 years (lower panel). As compared to males (Figure 3), health has been much more variable. Following 2005, health in pregnant females appears to be declining. Number of pregnant females in each year is shown in the top panel.

IMPACT/APPLICATIONS

The modeling efforts described here also have broad relevance in animal ecology. The elephant seal analysis provides insight into the details aspects of the physiological status of individual animals at fine spatial and temporal scales. Though our analysis takes advantage of a behavior that is unique to

elephant seals, it may possible to buoyancy as a proxy to estimate health for a large variety of marine mammal species (Aoki et al. 2011).

In addition to having relevance for other cetaceans, e.g. gray whales (Bradford et al. 2012), the right whale analysis provides a framework for analyzing many different mammalian species, including humans. By integrating sporadic observations with an underlying process model, we can infer how individuals are interacting with their environment, and how their health and condition is changing as a result. For example, these results provide an important baseline view of right whale health across a large variety of background environmental conditions. This could be used as a metric for understanding how disturbance may impact these whales, as development of offshore wind farms progresses.

This relationship between a disturbance the animal's health and ultimately its survival is the foundation of PCAD. The understanding of these links is critical for the Navy as it continues to assess what impact its activities may have on the health and survival of marine mammals.

RELATED PROJECTS

This project is closely related to two other ONR awards: N000141210389 to Scott Kraus (New England Aquarium), and N000141210274 to Erica Fleishman (UC-Davis).

PUBLICATIONS

Costa, D. P., L. Schwarz, P. W. Robinson, R. S. Schick, P. A. Morris, R. S. Condit, D. E. Crocker, and A. M. Kilpatrick. 2014. A Bioenergetics Approach to Understanding the Population Consequences of Disturbance: Elephant seals as a Model System. *in* A. N. Popper and A. Hawkins, editors. Effects of Noise on Aquatic Life II. Springer. [in press]

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